AFRL-RV-PS-
TP-2013-0004

AFRL-RV-PS-
TP-2013-0004

SPACE SURVEILLANCE TECH AREA BENEFITS FROM UNIVERSITY PARTNERSHIPS (POSTPRINT)

David Voss, et al.

ATA Aerospace
1300 Britt St SE
Albuquerque, NM 87123-3353

10 December 2013

Technical Paper

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

AIR FORCE RESEARCH LABORATORY
Space Vehicles Directorate
3550 Aberdeen Ave SE
AIR FORCE MATERIEL COMMAND
KIRTLAND AIR FORCE BASE, NM 87117-5776

DTIC COPY

NOTICE AND SIGNATURE PAGE

(AFRL-RV-PS-TP-2013-0004) HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

//SIGNED//

David Voss, WUM

//SIGNED//

JOEL B. MOZER, DR-IV
Chief, Integrated Experiments
and Evaluation Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
10-12-2013

2. REPORT TYPE
Technical Paper

3. DATES COVERED *(From - To)*
29-Jun-07 - 29-Oct-12

4. TITLE AND SUBTITLE
Space Surveillance Tech Area Benefits From University Partnerships (Postprint)

5a. CONTRACT NUMBER
FA9453-07-D-0189/0008

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62601F

6. AUTHOR(S)
David Voss, Kelly Cole, Amanda Pietruszewski, Lyon King, Philip Hohnstadt,
Kelly Feirstine, John Crassidis, Michael Angelo, Richard Linares

5d. PROJECT NUMBER
8809

5e. TASK NUMBER
PPM00004247

5f. WORK UNIT NUMBER
EF000357

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ATA Aerospace
1300 Britt St SE
Albuquerque, NM 87123-3353

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory
Space Vehicles Directorate
3550 Aberdeen Ave. SE
Kirtland AFB, NM 87117-5776

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/RVEP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-RV-PS-TP-2013-0004

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited. (377ABW-2011-1316 dtd 09/06/2011)

13. SUPPLEMENTARY NOTES
"Government Purpose Rights"
AMOS Conference, Maui, HI, 09/14/2011

14. ABSTRACT
The University Nanosat Program (UNP) is a two year small satellite competition held among leading universities across the nation. In the past 12 years UNP has involved 27 universities and over 4000 students in a variety of engineering fields and other disciplines in the process of designing and managing the development of a satellite. The UNP is a partnership between the Air Force Office of Scientific Research (AFOSR), the Air Force Research Laboratory (AFRL), and the American Institute of Aeronautics and Astronautics (AIAA). The program's primary purpose is to help train engineering students in satellite design, fabrication, and testing by requiring them to build the satellite themselves with the assistance of their Principle Investigator and industry mentors as well as a series of six program reviews managed by the AFRL Program Office. Each university-built satellite attempts to further a specific technology or perform a scientific mission. Technologies advanced through the program include all aspects of small satellite designs including structures, propulsion, imaging, and navigation and have helped further science payloads such as energetic particle detectors, plasma probes, and photometers. This paper will discuss the educational impact on students involved in a hands-on, hardware focused program, with emphasis given to two UNP satellites relevant to Space Surveillance Technologies. The most recent winner of the UNP competition, Michigan Technological University's Oculus-ASR, is a calibration satellite for AMOS's telescopic non-resolved object characterization program. Another example is the University of Buffalo, which is collaborating with the AFRL MESSA program in the current competition cycle. The University of Buffalo's microsatellite is being designed to collect multi-band photometric data of glinting geostationary space objects. Both these satellites are excellent examples of the relevance and quality of innovation and technology that can be produced from an educational program. Finally, the paper will discuss how corporate and government sponsors are an important part of launching a successful educational flight experiment and are key benefactors from the data gleaned from a successful mission. These strong partnerships result in students working on relevant projects with mission driven requirements, creating a better educational program and a greater return on the investment of external partners.

15. SUBJECT TERMS
University Nanosat Program (UNP)

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
UNCL	UNCL	UNCL	Unlimited	16	David Voss
					19b. TELEPHONE NUMBER *(include area code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

This page is intentionally left blank.

Space Surveillance Tech Area Benefits From University Partnerships

Kelly Cole, David Voss, Amanda Pietruszewski
Air Force Research Labs Flight Programs Branch (AFRL/RVEP)
Air Force Research Labs Space Experiments and Programs Branch (AFRL/RVEP)
3550 Aberdeen Ave SE, Albuquerque, NM 87113; 505.853.2947

Lyon B. King and Philip Hohnstadt
Michigan Technological University
Department of Mechanical Engineering – Engineering Mechanics
1400 Townsend Drive, Houghton, MI 49931

Kelly Feirstine
Schafer Corporation
2309 Renard Place SE, Suite 300, Albuquerque, NM 87106; (505) 338-2867

John Crassidis, Michael D'Angelo, and Richard Linares
University at Buffalo
Department of Mechanical and Aerospace Engineering
1007 Furnas Hall, Buffalo, NY 14260

ABSTRACT

The University Nanosat Program (UNP) is a two year small satellite competition held among leading universities across the nation. In the past 12 years UNP has involved 27 universities and over 4000 students in a variety of engineering fields and other disciplines in the process of designing and managing the development of a satellite. The UNP is a partnership between the Air Force Office of Scientific Research (AFOSR), the Air Force Research Laboratory (AFRL), and the American Institute of Aeronautics and Astronautics (AIAA). The program's primary purpose is to help train engineering students in satellite design, fabrication, and testing by requiring them to build the satellite themselves with the assistance of their Principle Investigator and industry mentors as well as a series of six program reviews managed by the AFRL Program Office. Each university-built satellite attempts to further a specific technology or perform a scientific mission. Technologies advanced through the program include all aspects of small satellite designs including structures, propulsion, imaging, and navigation and have helped further science payloads such as energetic particle detectors, plasma probes, and photometers. This paper will discuss the educational impact on students involved in a hands-on, hardware focused program, with emphasis given to two UNP satellites relevant to Space Surveillance Technologies. The most recent winner of the UNP competition, Michigan Technological University's Oculus-ASR, is a calibration satellite for AMOS's telescopic non-resolved object characterization program. Another example is the University of Buffalo, which is collaborating with the AFRL MESSA program in the current competition cycle. The University of Buffalo's microsatellite is being designed to collect multi-band photometric data of glinting geostationary space objects. Both these satellites are excellent examples of the relevance and quality of innovation and technology that can be produced from an educational program. Finally, the paper will discuss how corporate and government sponsors are an important part of launching a successful educational flight experiment and are key benefactors from the data gleaned from a successful mission. These strong partnerships result in students working on relevant projects with mission driven requirements, creating a better educational program and a greater return on the investment of external partners.

1. INTRODUCTION

The University Nanosat Program (UNP) began in 1998 and is a partnership between the Air Force Office of Scientific Research (AFOSR), the Air Force Research Labs (AFRL), and the American Institute of Aeronautics and Astronautics (AIAA). The program's original mission was twofold: address the dwindling number of aerospace engineers and investigate the ability to build inexpensive satellites. Both objectives have been a resounding success, having involved thousands of students in satellite fabrication programs across the country giving them hands-on experience and making them higher qualified systems and technical engineers, many of which have since been hired by the DOD or competitively swept up by aerospace companies. The ability to build inexpensive satellites and resulting technologies was proven on flight in the Fall of 2010 with the University of Texas-Austin's microsat FASTRAC, or Formation Autonomous Satellite with Thrust, Rel-nav and Crosslink, which has been collecting on-orbit data that will be compiled and used to augment national databases.

Based on these successes, as well as many lessons learned, the UNP Program has re-shaped its mission, raising the bar for future student-built satellites. There are currently five UNP spacecraft in the final stages of development, three of which are scheduled to launch in 2012. Because it has become obvious that inexpensive student-built satellites are achievable and can produce capable missions, the issue now becomes how to encourage those missions to be DOD relevant. Not only does AFRL want a working student-built satellite, but one that produces a useful mission for furthering DOD capabilities – whether that be by increasing technology readiness levels, partnering with an existing program that cannot afford building a bus platform, or a science mission that augments incomplete databases (providing all material is in the public domain). There are many relevant missions for the schools to consider, the emphasis remaining on the fact that each individual program is still owned wholly by the respective university and must make mission related decisions only based on DOD guidance rather than demand. However, in order to be chosen for flight, relevance has become much more of a weighted factor, encouraging the schools to seek that guidance more readily.

The good example of this is Michigan Technological University's Oculus-ASR, which is the newest UNP flight program. It is currently scheduled to be ready for launch in 2013 and has been briefed to the AFRL Space Experiment Review Board (SERB). Oculus-ASR has two key customers: the Air Force Maui Optical Site (AMOS) facility and the Multi-sensor Exploitation for Space Situational Awareness (MESSA) program. These DOD partners have helped define their requirements and shape their mission. MTU has also reached out to companies for hardware donations and opportunities to increase technical readiness levels (TRLs), creating a mutually-beneficial partnership in which the school acquires quality equipment they would not be able to afford on their own and the company is able to obtain flight time and on-orbit data. Without partnerships such as these, a school would not be able to deliver as high quality a satellite, decreasing relevance or delaying delivery time.

A second example of how schools are increasing their DOD relevance is with the University of Buffalo's Glint Analyzing Data Observation Satellite (GLADOS). Buffalo is in the current UNP competition cycle and has just completed their Preliminary Design Review, held in conjunction with the USU Small Satellite Conference. As their mission is forming, they are reaching out to AMOS and MESSA, seeking aide in relevance and design mentorship. Their current mission is to observe glinting objects in Geostationary Orbit from their spacecraft in a Low Earth Orbit. It is hoped that the data will aide in the determination of the object's shape, attitude maneuvers, and external materials. As Buffalo builds their program, they will need to follow in MTU's footsteps of seeking industry partnerships and following closely the needs of their sponsors.

These two examples clearly show the importance of encouraging universities to participate in student satellite programs, partnering with DOD and industry for everyone's benefit.

2. THE UNIVERSITY NANOSAT PROGRAM

The three UNP partners each have a specific and unique role. AFOSR provides funds for the development of the satellites at each school; AFRL supplies the program staff to organize and manage the competition including programmatic and technical oversight, spacecraft testing and launch vehicle integration; and AIAA funds the Flight Competition Review where the program performs its down-select.

As explained in “Real Science, Real Education: The University Nanosat Program”, there are three goals to the University Nanosat Program that underpin all programmatic events, as seen in Fig. 1 [1]. The primary goal is educating the next generation of spacecraft engineers and is composed of two priorities: the advancement of systems engineering students and students with experience in hardware integration, test and flight operations. The systems engineering students mentioned are those who have worked on hardware and understand their subsystem is a component of a larger system. The goal of the program in this regard is to force students to learn the hard lessons of engineering by allowing them to do it themselves. The secondary and tertiary objectives of the program have strong benefits to the aerospace community through the development of capable, small satellite technologies and the development of satellite hardware labs at U.S. universities.

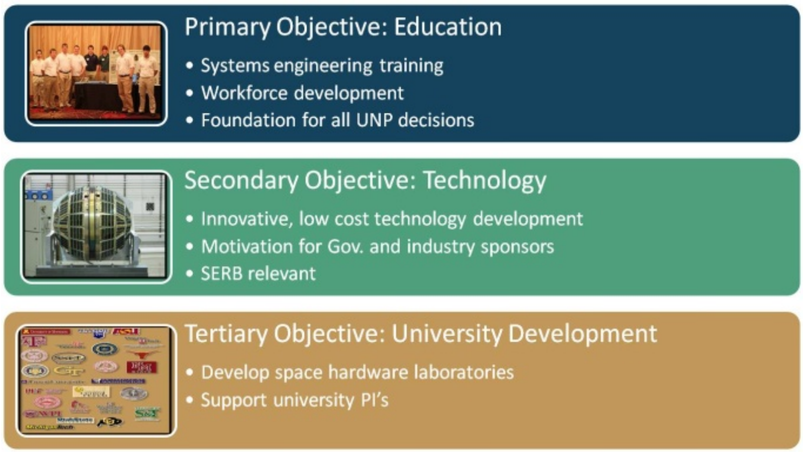


Fig. 1 The three objectives of UNP: the Program Office is required to balance these sometimes competing priorities.

Every competition cycle is designated as NS-X, where the X is a number that increments each cycle. The current cycle is NS-7, and the most recent winner working toward delivery is the NS-6 winner. The NS-4, NS-5, and NS-6 winners are all still in various stages of development. NS-4 is going through environmental testing, NS-5 is scheduled to deliver to AFRL this Fall, and NS-6 has just begun the post-competition process. The structure of the University Nanosat Program is built around a series of 10 scheduled milestones over the course of two years: a kick-off meeting, six design reviews, and three skill building events with a focus on education and team development. It is expected at each milestone that the students are the presenters with support from their Principle Investigator. This milestone based schedule enables the UNP Program Office to keep track of each university’s design progress, as well as introduce potential partners and investors along the way with the ability to showcase the school at reviews. The Flight Competition Review (FCR) is the closing event in which at least one school of the eleven competitors is chosen for funding to complete their design and get the opportunity to launch. The other schools are encouraged to find flights on their own with possible support from the Program Office.

Once a winner is chosen, a new milestone schedule is established, leading the university team to design completion and delivery to AFRL for final environmental testing and launch preparation. At least four more reviews, along with progress checks and university-led test requirements, must be passed before delivery of the satellite is accepted at AFRL. This process is another two years, making it a total of four years from Kickoff to Delivery for the winning school. It is important to keep this schedule as firm as possible due to the cyclical nature of college students graduating and the need to keep the relevant knowledge-base high throughout the design process.

3. MICHIGAN TECHOLOGICAL UNIVERSITY

The most recent winner of the UNP competition is NS-6's Oculus-ASR, designed and built by Michigan Technological University. There are many factors that have contributed to MTU's success, to include a knowledgeable group of professors willing to mentor and lead, facilities at the campus for test and design, and motivated students who stay involved year after year. However, a large contributing factor to this school, and any school's final satellite completion, is their partnerships with both DOD and industry programs. MTU has developed relationships with two invested customers: the Air Force Maui Optical Site (AMOS) facility and the Multi-sensor Exploitation for Space Situational Awareness (MESSA) program. MTU has shaped their mission and design to meet the needs of the end user, deriving requirements based on guidance from both AMOS and MESSA.

Oculus-ASR's mission is to provide calibration opportunities for ground-based observers attempting to validate and/or anchor algorithms capable of determining spacecraft attitude and configuration using unresolved optical imagery. To this end, the optical signature of the vehicle has been extensively characterized in ground facilities, and once on orbit Oculus-ASR will serve as a cooperative imaging target for ground-based telescopes owned by AFRL's AMOS facility. Ground controllers at MTU will command the vehicle to perform various attitude maneuvers during flyovers of these telescopes. After each ground-viewing opportunity the MTU team will provide attitude truth history to the telescope observers for comparison with their findings.

3.1 Vehicle Overview

As described in "Pre-launch Optical Characterization of the Oculus-ASR Nanosatellite for Attitude and Shape Recognition Experiments", Oculus-ASR is a 70-kg satellite with a volume envelope of 50 cm by 50 cm by 80 cm [2]. It consists of two modules that are permanently attached. An octagonal module, referred to as the Oculus module, sits atop a square module, known as the Attitude and Shape Reconfigurable (ASR) module. Fig. 2 shows the assembled vehicle and identifies the major features on the exterior of the satellite.

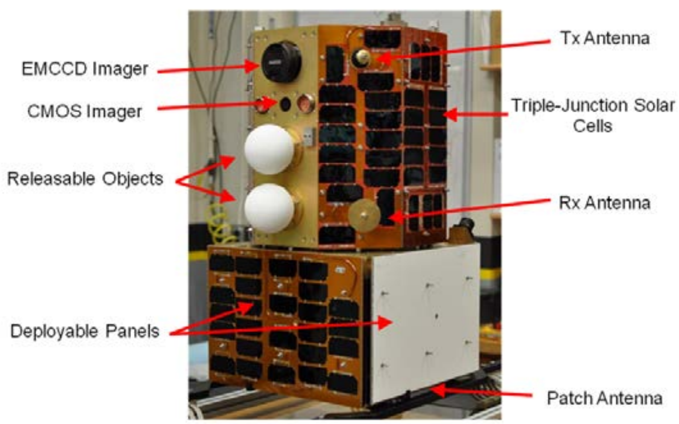


Fig. 2 The Oculus-ASR Vehicle

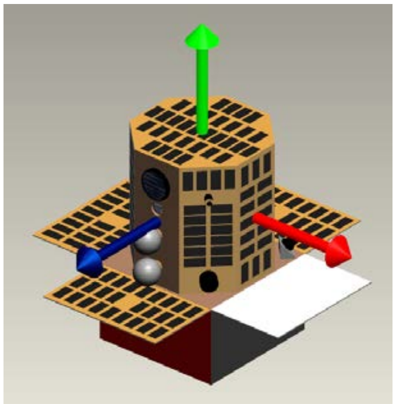
Each of the four sides on the ASR module has a deployable panel. Three of these panels are covered in solar cells. The fourth is covered in Duraflect material. Duraflect is a highly reflective, diffuse white coating used as an optical standard for characterization and calibration measurements. On the back of each deployable panel are specific materials requested by the AMOS telescope operators for their distinct spectral characteristics. These materials are red, blue, yellow, and clear anodized aluminum. Each panel is deployed separately through Frangibolt actuators. Spring-loaded hinges then lift the panel until it locks in place 90° from its undeployed position. These deployable panels allow the spectral signature of Oculus-ASR to be changed multiple times over the course of the mission by altering the vehicle's shape and exposed materials.

Two releasable spheres are mounted to the Oculus module. These objects are approximately 10 cm in diameter and will be used to provide ground observers an opportunity to view small, closely spaced objects. The releasable objects are coated in the same Duraflect material used on the deployable panel, and can be released individually using the same style of Frangibolt actuator used for the deployable panels. These objects then drift from the vehicle due to the force exerted from the actuator.

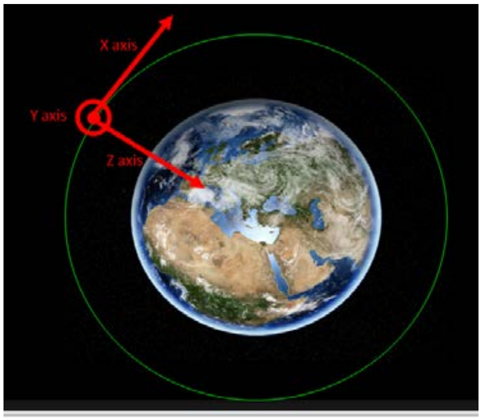
The satellite is capable of 3-axis attitude determination and control. This allows Oculus-ASR to perform a wide variety of attitude maneuvers for telescope calibration purposes. Attitude determination is accomplished using a magnetometer and three gyroscopes. These sensors provide an attitude reading accurate to within 5 degrees of error. Three reaction wheels and three magnetic torque rods are currently planned to control the vehicle's attitude. Both reaction wheels and torque rods were developed in-house at Michigan Technological University. Each magnetic torque rod can generate approximately 285 μN·m of torque. A single reaction wheel is capable of 11 mN·m of torque. The reaction wheels allow the vehicle to achieve an angular velocity of 7.5 °/s on its x- and y- axes and up to 17 °/s on its z axis.

3.2 Concept of Operations

Oculus-ASR will exercise three key capabilities of the ground based telescopes using unresolved optical imagery: determine the spacecraft's attitude, detect configuration changes, and measure the change in signature due to a small resident space object in close vicinity to the main vehicle. On-orbit, one of Oculus-ASR's roles will be to fulfill requests to view specific attitude profiles during overpasses of the observatory. These attitude profiles are described in regard to a body coordinate system (BCS) and an orbital coordinate system. Fig.3 depicts these coordinate systems.



(a)



(b)

Fig. 3 Body Coordinate System (a) and Orbital Coordinate System (b) used to define the attitude of Oculus-ASR.

Telescope operators may select maneuvers from a list of predetermined attitude profiles. These include:

Ready: Rotation rate about any axis is less than 2 °/s; the angles between the BCS and Orbital Coordinate System are uncontrolled.

Fixed-Axis Rotation: Any single body coordinate axis is fixed with respect to the Orbital Coordinate System; constant rotation rate about the fixed axis, no rotation about any other axis.

Earth Pointing: A vector in the BCS is kept pointed at a fixed location on the Earth's surface.

Orbital Coordinate System Fixed Attitude: Constant angles between the BCS and Orbital Coordinate System with zero rotation; attitude is constant with respect to the Orbital Coordinate System

Sun Pointing: A vector in the BCS is kept pointed at the Sun.

Observatories will schedule these maneuvers with the operators of Oculus-ASR in advance of an observation opportunity. At all times, Oculus-ASR will be recording a time-indexed history of its attitude. After an overpass maneuver, this attitude history will be downloaded to the MTU ground station, where it will be delivered to the telescope operators. The customers will then be able to use the truth attitude from the vehicle and the models developed through the ground characterization of the vehicle to determine if the telescope was providing readings accurate enough to determine Oculus-ASR's attitude during the observation. After establishing baseline measurements of the vehicle in its as-launched configuration, telescope operators will request the deployment of a panel. The operators of Oculus-ASR will command the deployment and confirm the successful opening of a panel. Telescope operators can then take further measurements and compare these to the baseline measurements in order to determine which panel was opened and when the actuation occurred.

Finally, Oculus-ASR is equipped with two releasable objects. These objects are much smaller than Oculus-ASR. After an object is released, it drifts slowly from the vehicle. The goal of the telescope operators is to determine if and when this small object can be detected and distinguished from the Oculus-ASR. The ideal method of accomplishing this will be to release the object at the beginning of the first of two consecutive overpasses of an observatory. This gives telescope operators an additional opportunity to view the satellite and the separated object in the event that the separation cannot be detected during the first observation opportunity. Vital to all of these operations is having a complete radiometric characterization of the vehicle prior to launch. This characterization yields models that can be used as truth values to which the experimental measurements taken from the telescopes can be compared.

3.3 DOD Partners and Pre-launch Characterization

SSA relies not only on measurements of space objects but on an understanding of what those measurements mean. In order to understand the signatures of space objects, it is necessary to measure, model, and simulate a spacecraft's spectral characteristics. One of the objectives of the Oculus-ASR characterization experiment is to provide ground-truth satellite data for the construction and validation of predictive computer models such as those used in Time-domain Analysis Simulation for Advanced Tracking (TASAT), a satellite modeling code used throughout the SSA community. Another objective of this experiment is to establish if pose determination is possible solely from on-orbit spectral returns. Imaging the satellite on the ground will help ascertain whether this objective can be met.

Multispectral optical measurements of Oculus-ASR satellite were conducted at an AFRL far-field optical measurement facility by the MESSA Program. This facility allows accurately simulated observations of space objects without significant atmospheric effects. This ability provides the opportunity to measure the optical signatures of satellites and then modify corresponding satellite models to improve agreement with these ground-truth optical signatures. This characterization experiment obtained accurate far-field imagery, Optical Cross Section (OCS), and spectral-polarimetric glint and off-glint data helpful in validating remote observations.

The use of anodized colored panels on the Oculus-ASR satellite base is intended for the purpose of inferring satellite pose or attitude from observations. Satellite imagery for typical on-orbit viewing geometries will not be resolved. In certain poses, when the satellite is observed from the ground, metallic glints or non-colored panel reflections will often dominate the OCS and mask the colored panel contributions. It is important to understand which spectral filtered wavebands will contribute the most attitude information.

Partnerships like these are a key benefit for the DOD in regards to workforce and technology development. MTU is flying as a calibration satellite for telescopes at AMOS and simulation software at both AMOS and MESSA. By creating observation opportunities with known bus configuration changes, prediction results can be compared with actual observations. A need in the Space Surveillance capability is being met with 50 students from a university undergrad program. That is an impressive cost savings for the DOD, also resulting in educational benefits that will reap rewards for years to come.

3.4 <u>Industry Partners – Mentorship and Hardware</u>

Small satellites can be developed within a university environment for considerably less cost than a comparable program within government or industry. While industry and government engineers are professionals that must be compensated at the market rate, student engineers benefit from the educational experience rather than direct monetary compensation and, thus, the labor costs for university spacecraft design are orders of magnitude less than in industry (although the program must accept the higher risk associated with such programs). However, the widgets, actuators, and hardware that make up a spacecraft can still represent insurmountable costs for many university programs. Fortunately, student satellite flight opportunities represent an ideal venue for collaboration between universities and industry and these collaborations can be used to mitigate hardware budget challenges.

The Oculus-ASR program enjoys collaboration with industry partners. While the detailed arrangement of each partnership is different, some features are common to all of the agreements: (1) industry partners provide hardware donations that enhance or enable mission objectives at greatly discounted or waived costs, (2) technical representatives from the companies maintain contact with the program by participating in design reviews, telecons, and on-campus visits, and (3) upon successful flight the university shares relevant data related to the component with the sponsor. While some partner companies are primarily interested in flight data from their component, many representatives relate that it is the opportunity to observe, interact with, and cultivate talented young engineers who are just about to enter the workforce that motivates their donation. Indeed, MTU can cite numerous success stories where partner companies recruited and hired the top-performing students from the spacecraft design program via relationships formed through the collaboration. These corporate investments in human resources can pay greater dividends than the tangible data product from the donated component.

In addition to enabling the core mission for a university satellite, industry partnerships often shape and influence the mission goals because of the enhanced capabilities. An example of this is the imaging mission of Oculus-ASR. At mission conception it was MTU's goal to image resident space objects in the local vicinity of the Oculus-ASR spacecraft. In order to achieve this mission MTU worked with collaborator Raytheon Missile Systems who donated a sensitive electron-multiplied CCD camera for space-to-space imaging. The camera donated by Raytheon far exceeded the performance requirements of the mission and, as such, the imaging mission objectives were extended in order to exercise the full capability of the device. Because the acquisition range was extended to take advantage of the low-light sensitivity of the EMCCD device the field-of-view for the optics was reduced so that distant objects could be resolved. However, the FOV was reduced such that it would be impossible to image released objects in very near proximity (~10 meters). To fill this gap, collaborator SAIC offered a space-rated Microspace camera with a wide field-of-view that now serves as the close proximity sensor. Operating together the two imagers overburdened the spacecraft power system, which originally relied on low-efficiency solar cells. At this juncture ABSL Power agreed to donate space-rated Li-ion batteries and Spectrolab (a Boeing company) matched with high-efficiency solar cells and interconnect kits. The students benefit from the ability to work with state-of-the-art components and instruments and also from their interactions with the corporate technical advisors.

4. THE UNIVERSITY OF BUFFALO

University at Buffalo (UB) students are currently developing a nanosatellite design as part of UNP-7 to address key technologies in SSA. UB aims to study spectrometric optical signatures of glinting Space Objects (SOs) in Geostationary Orbits (GEO) to improve SO characterization. Electrical-Optical (EO) sensing is a key technology in SSA and has particular importance for tracking, detecting, and characterizing GEO SOs due to the ineffectiveness of radar and other sensing devices for GEO objects. The optical signature, or brightness, as a function of phase angle can provide information on the following characteristic of a SO: orientation [3], material properties [3], status and status change analysis [4], shape classes [5], solar panel offsets [5], and aging [6]. For detailed surface material characterization, spectrometric and/or multi-band photometric measurements are generally required [7]. UB aims to develop a small low-cost space-based platform with the goal to collect high accuracy spectral photometry data of SOs, in particular GEO SOs to observe unabbreviated glints for an extended glinting season.

Glint is a term used to denote specular reflection off of relatively flat surfaces when the reflected light spikes beyond the nominal diffuse signature. This occurs during times of favorable angles between an observer, a satellite and the Sun. In the case of GEO SOs, glints occur in a predictable manner near zero phase angle. This is due to the majority of GEO SOs having large solar panels designed to track the Sun where the solar panels remain orientated close to normal to the Sun vector. Some GEO SOs have an angle offset when tracking the Sun; this shifts the phase angle at which glints are observed.

For a phase angle of zero, GEO SOs are found to be in the Earth's shadow, as are all phase angles of less than approximately 8.5 degrees at GEO. The Earth's shadow is approximately 17 degrees at GEO altitude (approximately 35,800 km) and causes an eclipse season of roughly two weeks centered at each equinox for a given fixed ground observation site. GEO SOs enter the Earth's shadow only near the equinoxes, for up to 70 minutes per day. During the same period, satellites tend to brighten over several days, twice per year; this is when the orientation of the satellite favors glinting for a ground observer. Therefore, the equinox for GEO SOs defines the glinting season and the brightest glint observations can be observed during this season. A space-based platform can capture direct glint of GEO SOs for an extended glinting season. This is possible because a space-based platform can make observations outside of the Earth's shadow at zero phase angles and are not limited to a fixed ground observer location.

Wavelength dependent photometric properties for materials, such as solar array panels, milled aluminum, anodized aluminum, multi-layer insulation, and white paint, are available as part of the time domain analysis simulation for advanced tracking (TASAT) signature simulation software package [8]. These spectral features will have the maximum observability at the glint configuration since glinting has very high magnitude specular reflectance.

Space-based EO sensing has been successfully demonstrated through both the midcourse space experiment (MSX) [8] satellite and the space missile tracking system (SMTS) of the space-based infrared system (SBIRS) [9]. Due to the success of the Advanced Concept Technology Demonstration (ACTD) of the Mid-Course Space Experiment's Space Based Visible sensor [10], the Space Based Space Surveillance (SBSS) Pathfinder satellite mission was postponed. The SBSS system will detect and track space objects, e.g. satellites and orbital debris, to generate data that the Department of Defense will use in support of military operations. This includes the collection and processing of Space Object Identification (SOI) data [11]. The SBSS will show improvements in probability of event detection, time to detect events, sensitivity, and overall capacity.

The SBSS program will provide highly accurate photometric data using highly capable but large and expensive platforms. The sensor used for the SBSS will require, in addition to high accuracy photometry, accurate satellite positioning information. Therefore SBSS sensors are not optimized for low cost photometry because photometric data collection does not require high spatial resolution, but rather requires higher temporal resolution to track orientation changes that occur at faster rates. The use of nanosatellite platforms in combination with existing programs for collecting photometric data for tracking changes in the status of SOs can offer a game changing reduction in cost and size; thereby increasing the number of available sensors and moving toward a persistent space surveillance capability.

The science instruments under consideration include a wide field-of-view (WFOV) photon counting imager that will have star tracker functionality and a spectroscope capable of sampling a diverse frequency range. These instruments when used in combination will allow the collection of accurate data of space objects between magnitudes -6 and 16 over wavelengths 175-1100 nm (FUV-NIR) with an object separation of 70 km in the GEO belt. Other spectral ranges are being considered to give more accurate data on thermal dissipation of space objects. The guider camera will be used to point the spectroscope within the field of view of the spectroscope. The innovative use of a photon counting imager as a guider for the spectroscope requires precision attitude control but only rough inertial attitude knowledge. This precision will be obtained by an attitude determination and control system that has been designed with pointing capabilities to be accurate on the order of one arcminute. This ADCS will employ zero crossing vibration mitigation techniques to reduce jitter and allow for precise attitude stabilization. Other technology includes an onboard computer capable of reducing spectroscopy and image data in real time. The computer will also be capable of implementing closed loop attitude feedback utilizing the guider camera.

UB has established several industry and DOD partnerships, most notably with Orbital Science Corporation (OSC) and AFRL Space Vehicles Directorate with support from Dr. Moriba Jah. OSC under the direction of Dr. Quang Lam has agreed to allow our university to conduct testing and to "...help UB Nanosat to achieve maturity in design, personnel, and administration, and demonstrate their readiness for future projects, such as eventual flight." (Raymond Crough, Senior Director, OSC). A partnership with Andor Technology will allow UB to acquire and test a WFOV imager with photon counting capability. Other industry sponsors include ITK systems, which produces thermal modeling software for ESA which allows the UB team to very accurately model the spacecraft bus, and Cadence Corporation which generously donated electrical simulation software.

5. CONCLUSION

This paper has shown how Michigan Technological University, has built a collaborative relationship with two AFRL programs while meeting all of the educational objectives of the University Nanosat Program. These invested customers provide expert mentorship, helping to shape mission requirements and context for a valuable mission. MTU has also partnered with four private companies who have provided hardware previously out of reach to a university program. These mutually-beneficial ties allow the company to gain flight data with their product as well as support the development of their future workforce.

The University of Buffalo is an example of an up and coming satellite program which has the potential to assist in meeting the low-cost SSA objectives. The area of Space Surveillance is a broad need for the DOD and oftentimes a student's fresh and innovative perspective is able to contribute much to community.

The University Nanosat Program has been working with students like these across the country for over ten years, helping them develop satellite programs and produce competent engineers with hardware experience. These universities are seeking and finding partnerships with other DOD and industry programs, making themselves more relevant and technologically cutting-edge.

ACKNOWLEDGEMENTS

The University Nanosat Program, Michigan Technological University, and the University at Buffalo would like to thank the following organizations for their support of educational programs and for their efforts in making use of students as a valuable resource: Air Force Office of Scientific Research, American Institute for Aeronautics and Astronautics, Raytheon Company, SAIC, ABSL Power, and Spectrolab.

REFERENCES

1. Voss, D., Clements, J., Cole, K., Ford, M., Handy, C., Stovall, A., *Real Science, Real Education: The University Nanosat Program*, Proceedings 2011 Small Satellite Conference, 2011.
2. King, L., Hohnstadt, P., *Pre-launch Optical Characterization of the Oculus-ASR Nanosatellite for Attitude and Shape Recognition Experiments*, Proceedings 2011 Small Satellite Conference, 2011.
3. Vrba, F.J., Fliegel, H.F., and Warner, L.F., *Optical Brightness Measurements of GPS Block II, IIA, and IIR Satellites on Orbit*, Proceedings 2003 AMOS Technical Conference, 2003.
4. Payne, T.E., Gregory, S.E., Luu, K., *SSA Analysis of GEOS Photometric Signature Classifications and Solar Panel Offsets*, Proceedings 2006 AMOS Technical Conference. 667-673, 2006.
5. Payne, T.E., Gregory, S.A., Tombasco, J., Luu, K., and Durr, L., *Satellite Monitoring, Change Detection, and Characterization Using Non-Resolved Electro-Optical Data From a Small Aperture Telescope*, Proceedings 2007 AMOS Technical Conference, 450-463, 2007.
6. Payne, T.E., Gregory, S.A., Vrba, F.J., and Luu, K., *Utility of a Multi-Color Photometric Database*, Proceedings 2005 AMOS Technical Conference, 137-145, 2005.
7. Jorgensen, K., *Using Reflectance Spectroscopy to Determine Material Type of Orbital Debris*, Ph.D. Thesis, Univ. of Colorado, Boulder, May 2000.
8. Abbot, R., Gaposchkin, E M., von Braun, C., *Midcourse Space Experiment Precision Ephemeris*, Journal of Guidance, Control, And Dynamics Vol. 23, No. 1, January–February 2000.
9. Orblits, E., *The Space and Missile Traclking System Contribution to Planetary Defense: Detection of Asteroids and Comets with Earth-crossing Orbits*, Mars (Los Angeles, Calif.), Volume 16, Page 18.
10. Jayant Sharma, J., Stokes, G H., von Braun, C., Zollinger, G.,Wiseman., A J., *Toward Operational Space-Based Space Surveillance*, Lincoln Laboratory Journal, Volume 16, Number 2, 2007.
11. Fernandez, A J., *Military role in space control: A primer*. CRS Report for Congress, Washington, DC. 2004.

DISTRIBUTION LIST

DTIC/OCP 8725 John J. Kingman Rd, Suite 0944 Ft Belvoir, VA 22060-6218	1 cy
AFRL/RVIL Kirtland AFB, NM 87117-5776	2 cys
Official Record Copy AFRL/RVEP/David Voss	1 cy